Challenges when Architecting Vision Inference Systems for Transformer Models

AI Hardware Summit

September 2023 | Jeremy Roberson, Director of Inference SW |
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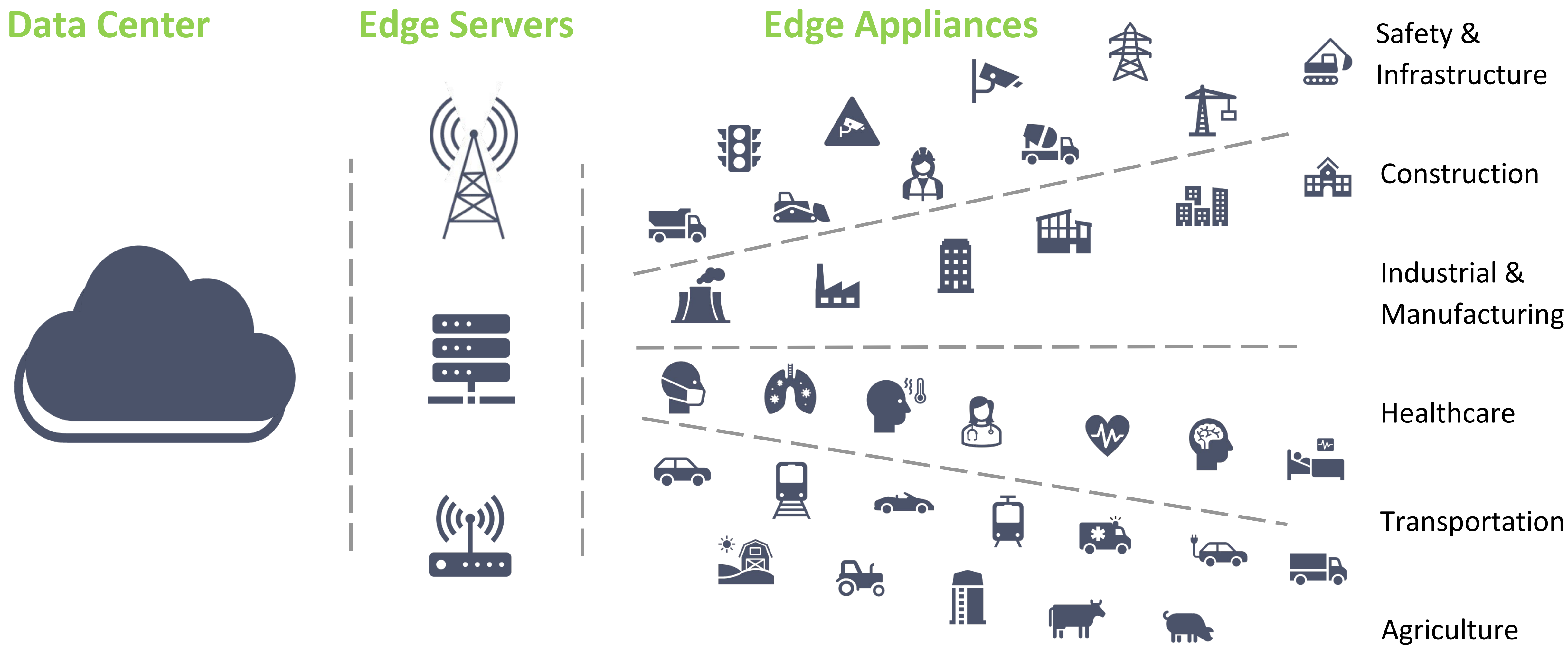
AI Landscape at the Edge is Dominated by Vision



Different requirements in **power** / **cost** / **performance**

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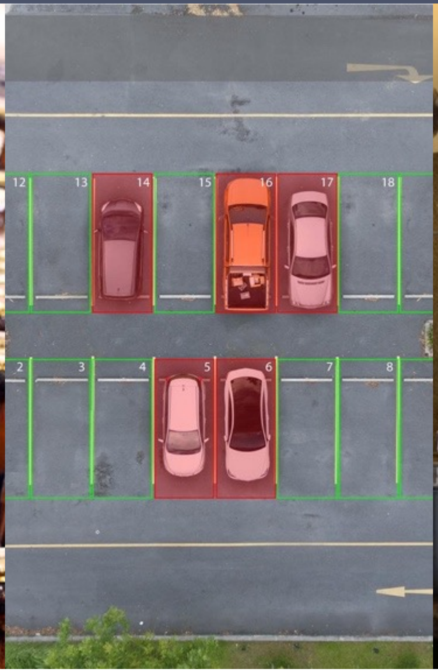
Markets and application

Safety & security

Manufacturing & industrial optical inspection



Traffic & parking management

Retail

Robotics

Agriculture

Embedded & Edge SoCs can benefit from AI Computer Vision

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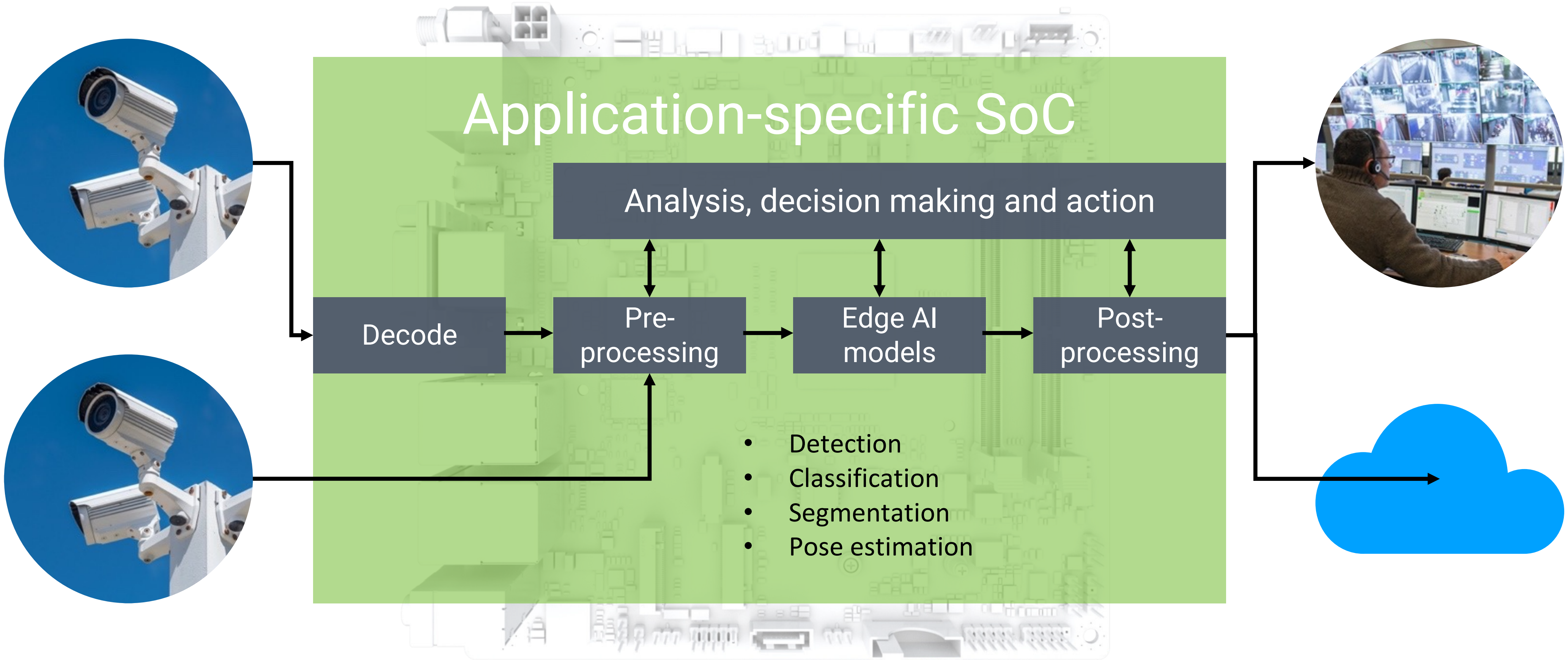
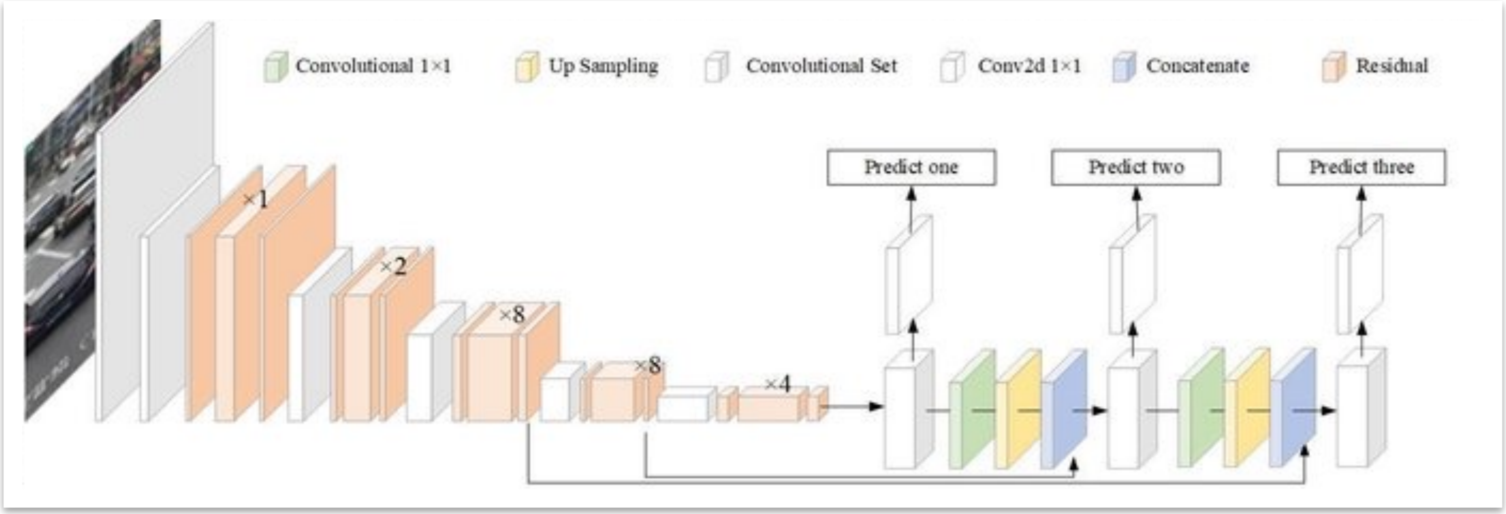
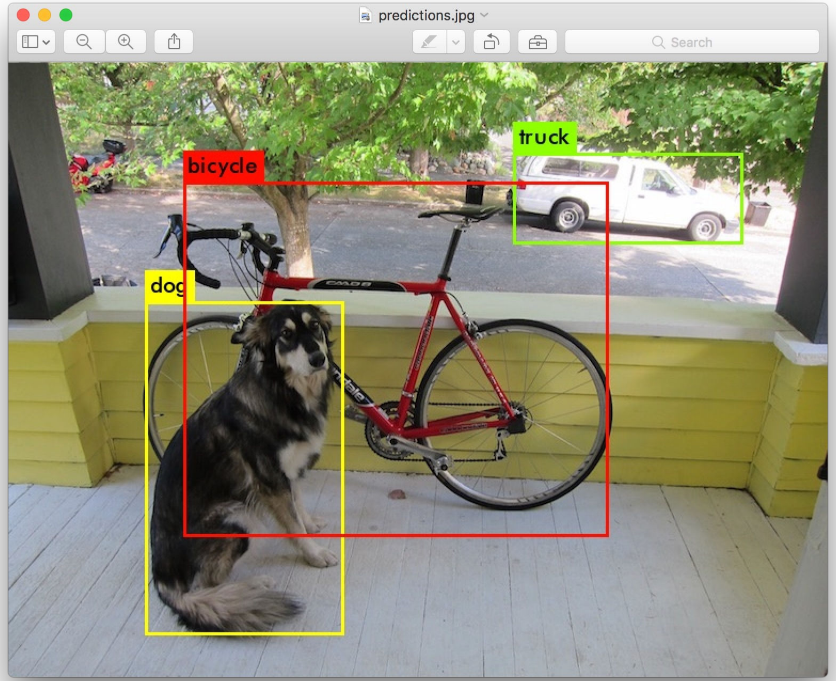
Typical Video and Vision Use cases



Convolutional Networks have fundamentally changed computer vision, but still have limitations





- YOLOv3 example:
- Operator Types: 3x3, 1x1, FC
- Total Layers: 75
- Output is object detection and location for trained categories
- Operations per Inference: 178B at 608x608

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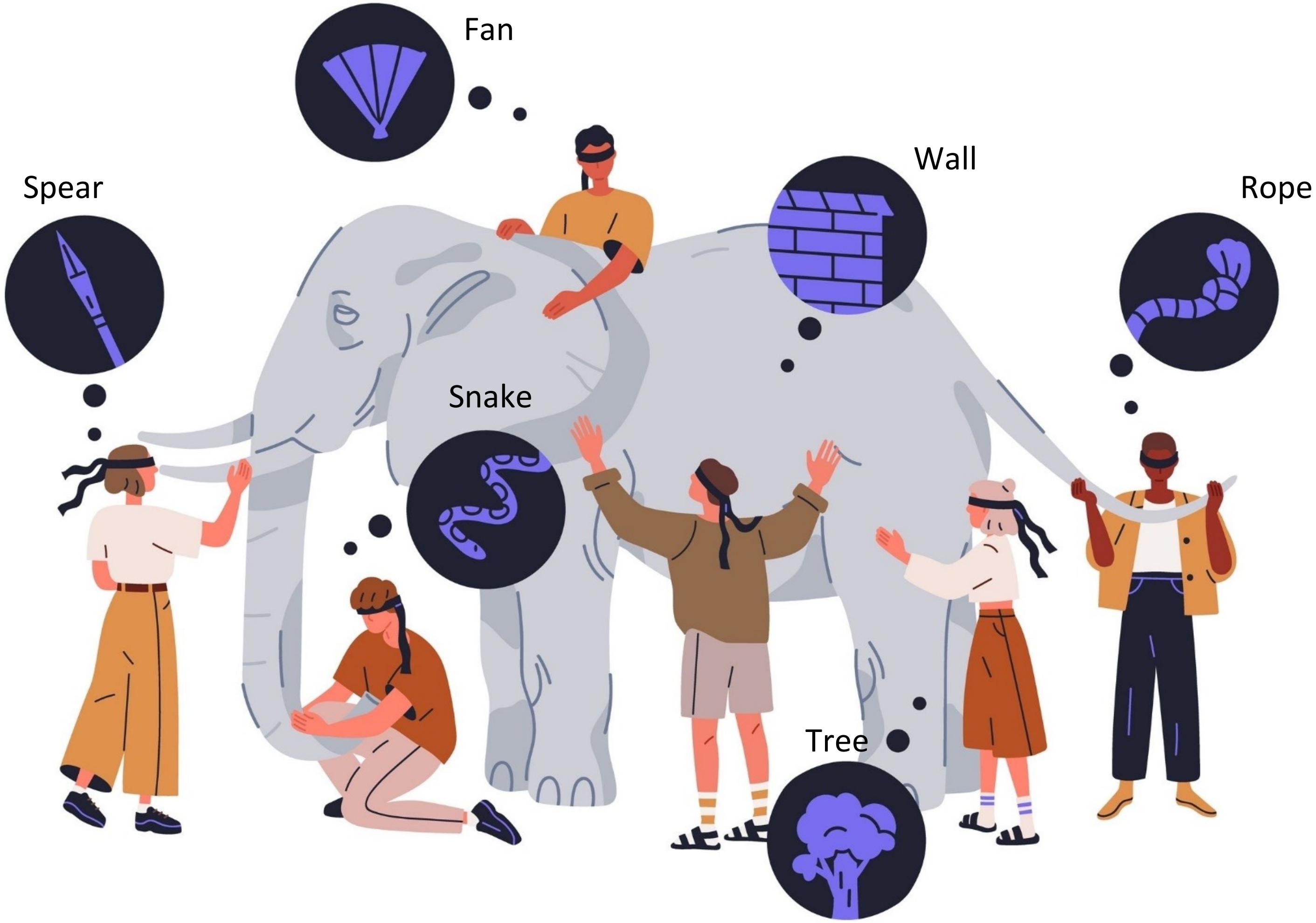
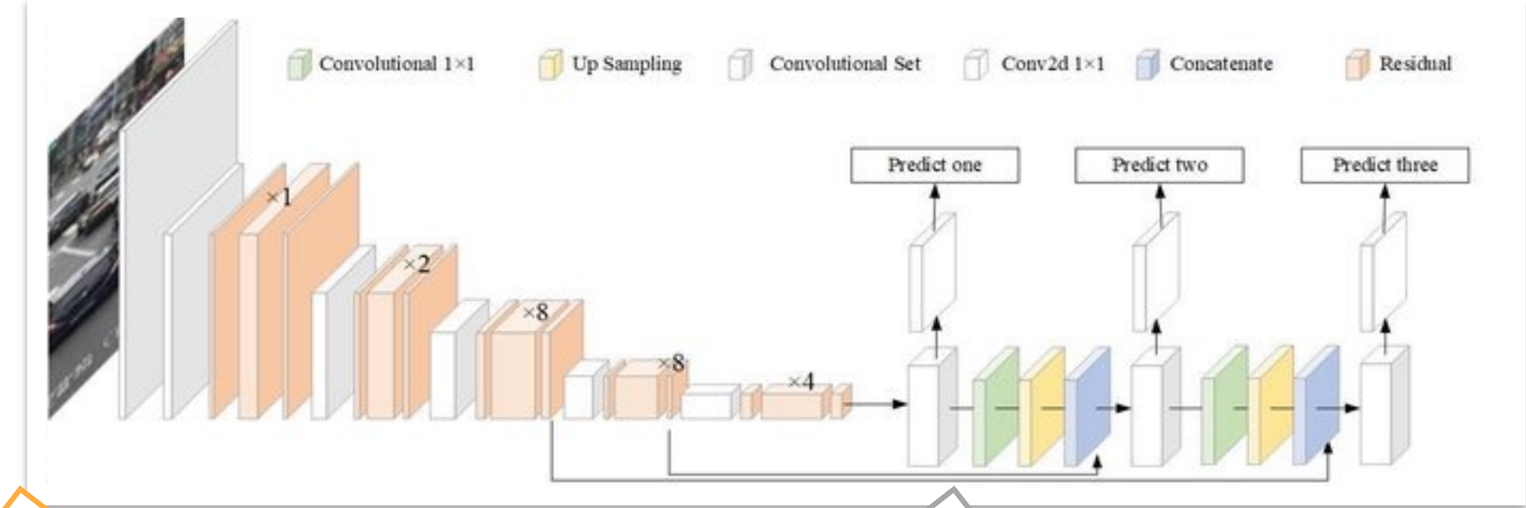
Blind person and the elephant – Receptive Field is a big limitation

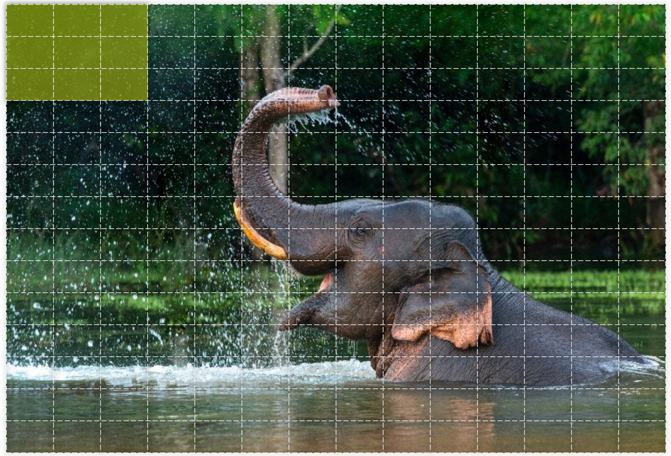


https://en.wikipedia.org/wiki/Blind_men_and_an_elephant#:~:text=The%20parable%20of%20the%20blind,the%20side%20or%20the%20tusk

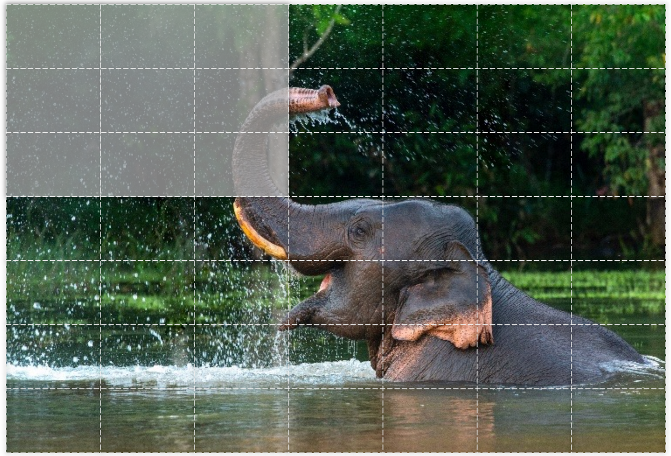
CNN uses larger filter size and down-sampling to increase receptive field, but insufficient



Smaller receptive field
Smaller features & objects



Larger receptive field
Larger features & objects



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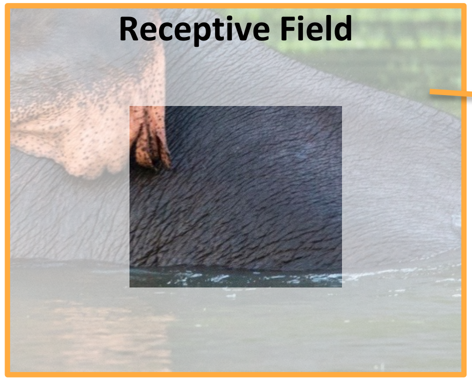
The difference between CNN and transformer models & their feature extraction

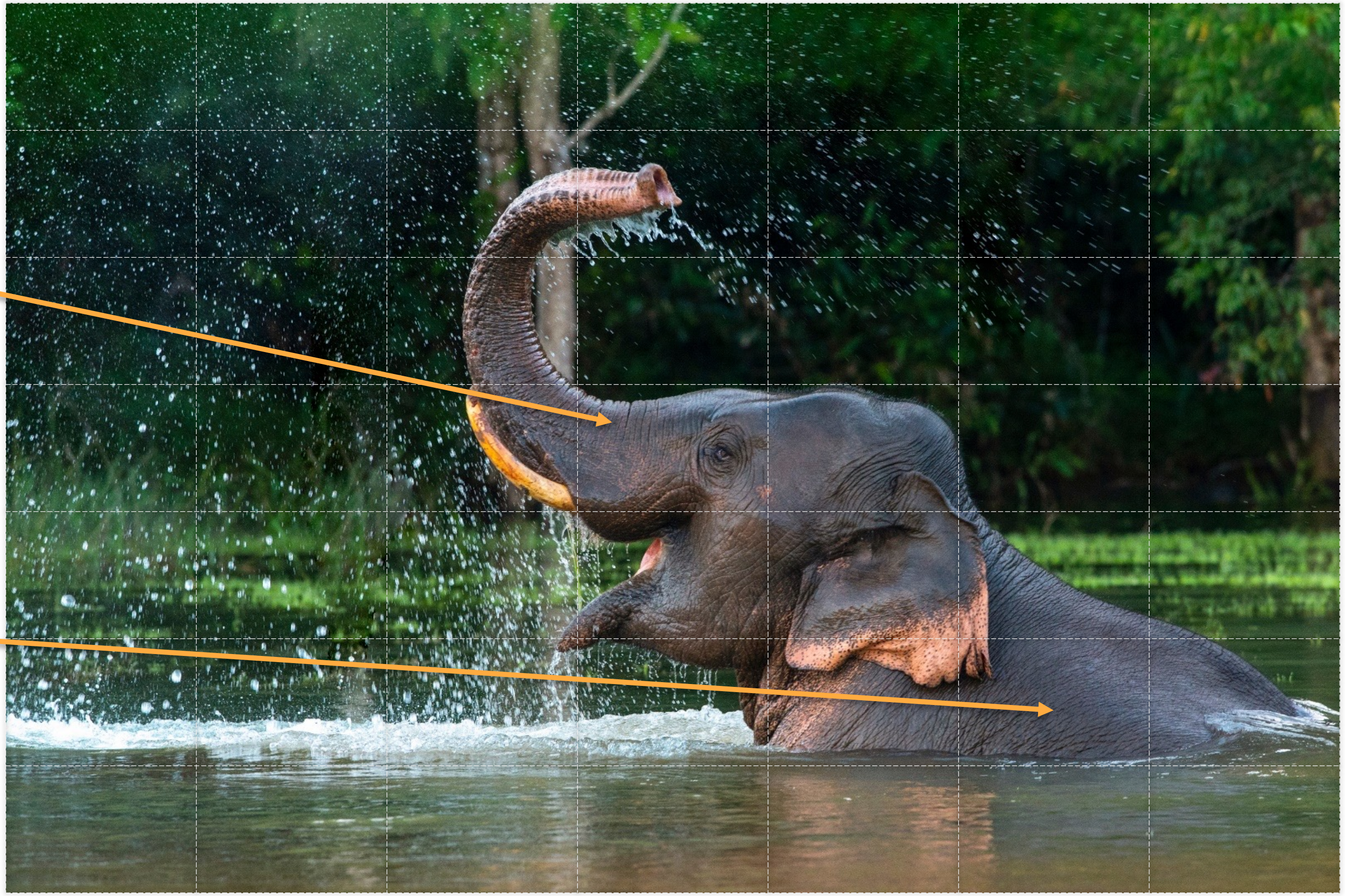
CNNs provide results with limited context

Transformer provide results in context

EASIER



VERY
HARD



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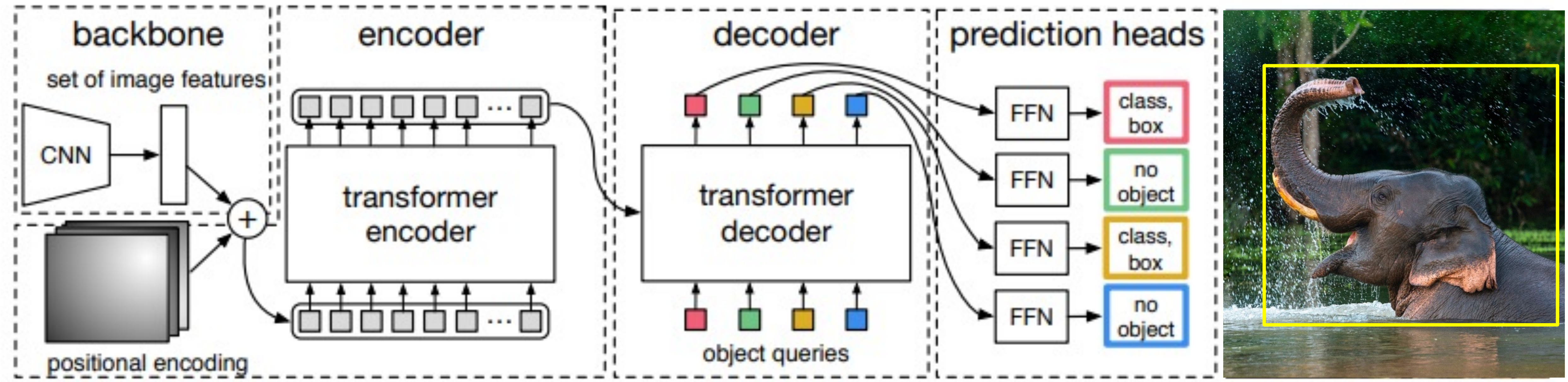
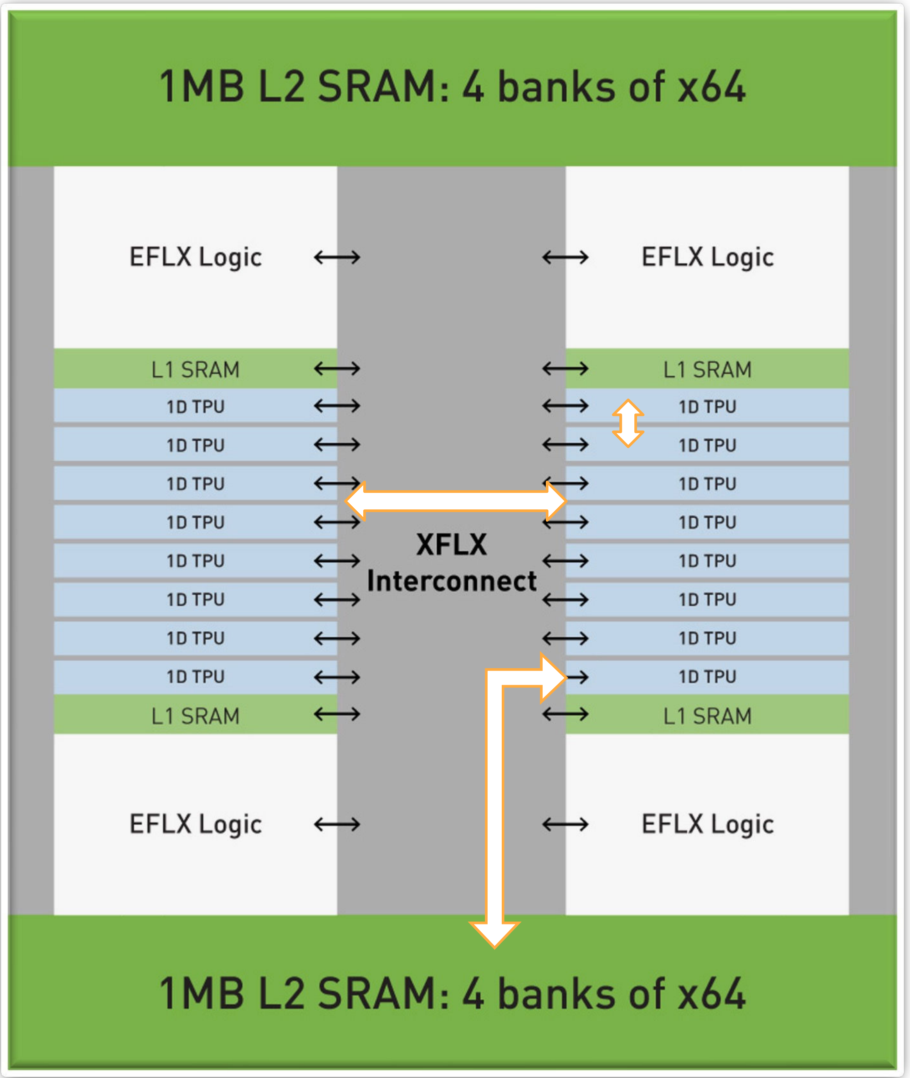
DETR 2020 - Combines CNN Backbone with Transformer-based Detector



- Still uses ResNet or similar CNN backbone for feature extraction
- But, the transformer prediction head is fundamentally different:
  - Encoder will extract features across all "patches" to gather overall context
  - Decoder stages then makes prediction based on encoder results
  - Encoder/decoder computation is very different from CNNs, not suitable for traditional accelerators

Dynamic TPU: Flexible, balanced & memory-efficient



Efficient data access:
Each 1D TPU core can stream data from:

- Neighboring 1D TPU (dedicated)
- Any 1D TPU (via XFLX)
- L2 SRAM (via XFLX)
- DDR & System memory (via NoC)

Flexible control and data path:

✓ “Future proof” compute, activations, and generic operators via EFLX
✓ X1 provides much more data bandwidth and manipulation vs NoC based AI engine
✓ X1’s flexibility include **mixed-precision support** – essential for supporting operators such as **transformers**

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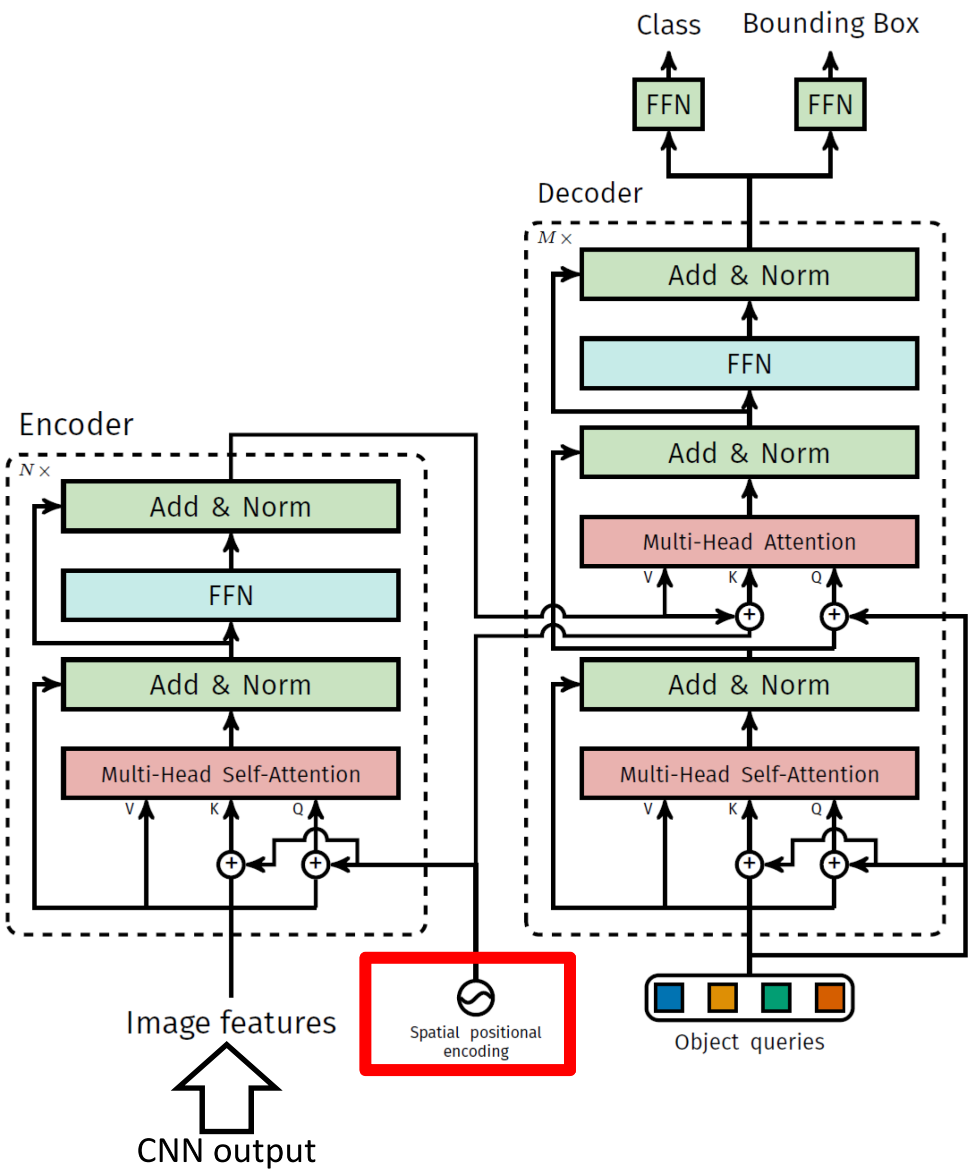
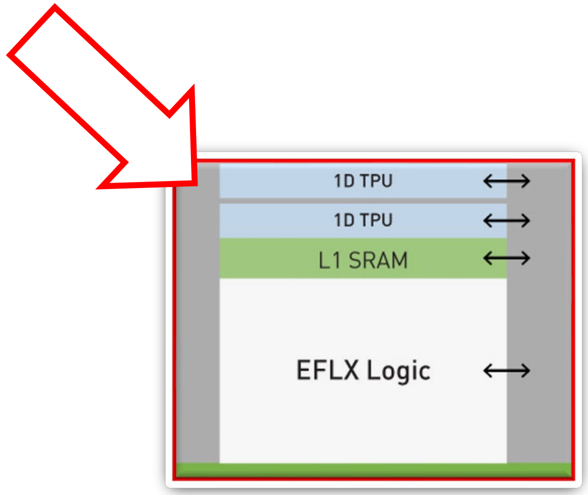
Diving into Vision Transformers (1)



First encoder stage is positional encoding:

- PE values are embedded into EFLX RAMs as ROM
- EFLX logic performs ROM look up "on the fly" prior to the V/K/Q attention head

$$PE_{(pos,2i)} = sin(pos/10000^{2i/d_{\text{model}}})$$
$$PE_{(pos,2i+1)} = cos(pos/10000^{2i/d_{\text{model}}})$$



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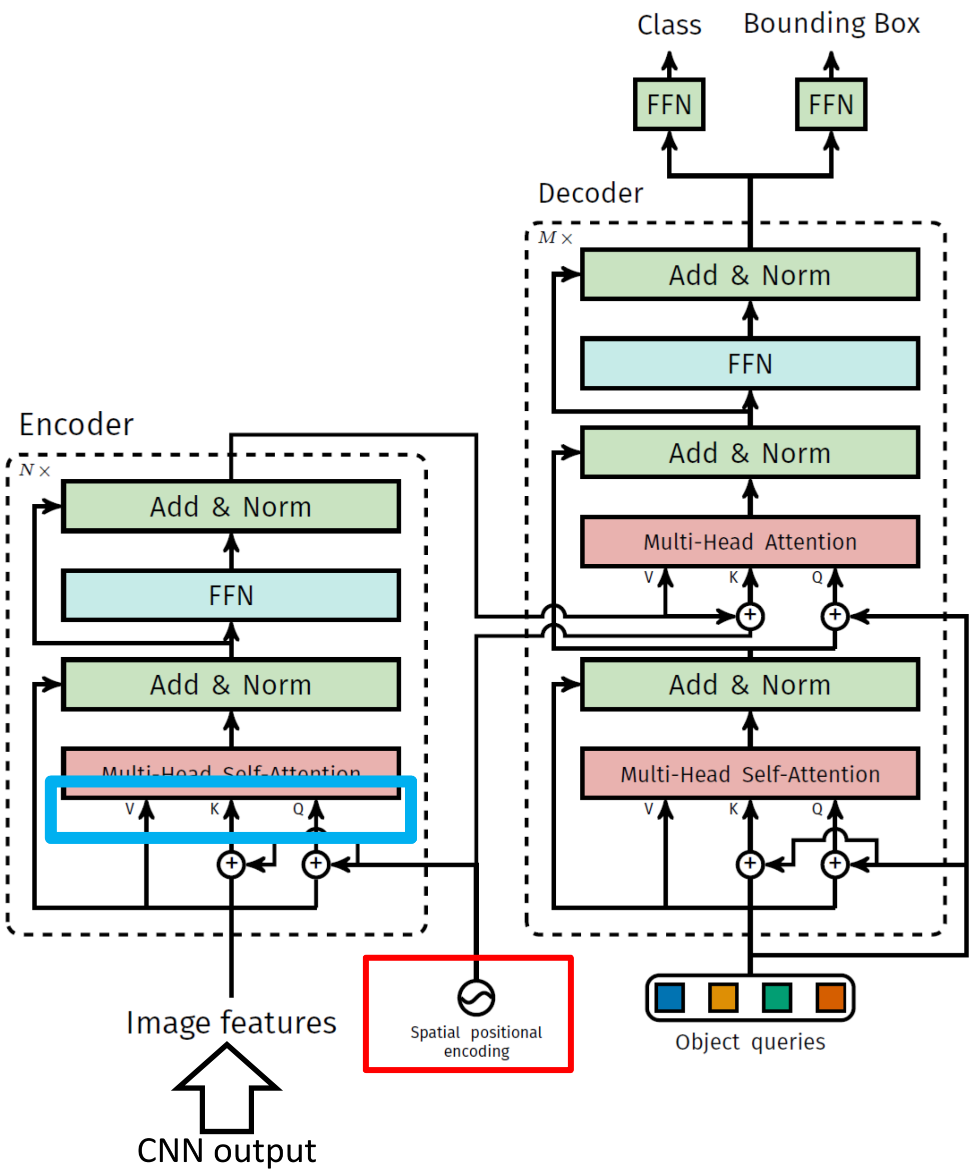
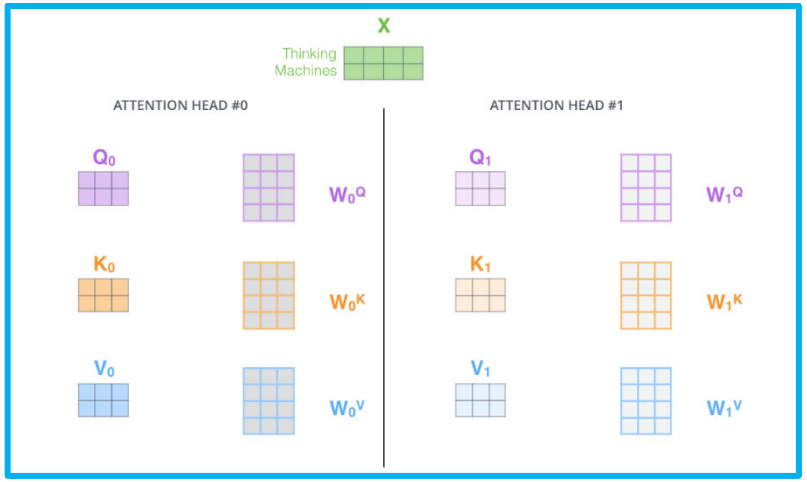
Diving into Vision Transformers (2)



Second encoder stage is the multi-head attention layer

- Starts by multiplying input data with 3 separate matrices (Q, K, V) for each attention head
- Natively maps onto our 1D-TPU with (Q, K, V) as weights



*https://jalammar.github.io/illustrated-transformer

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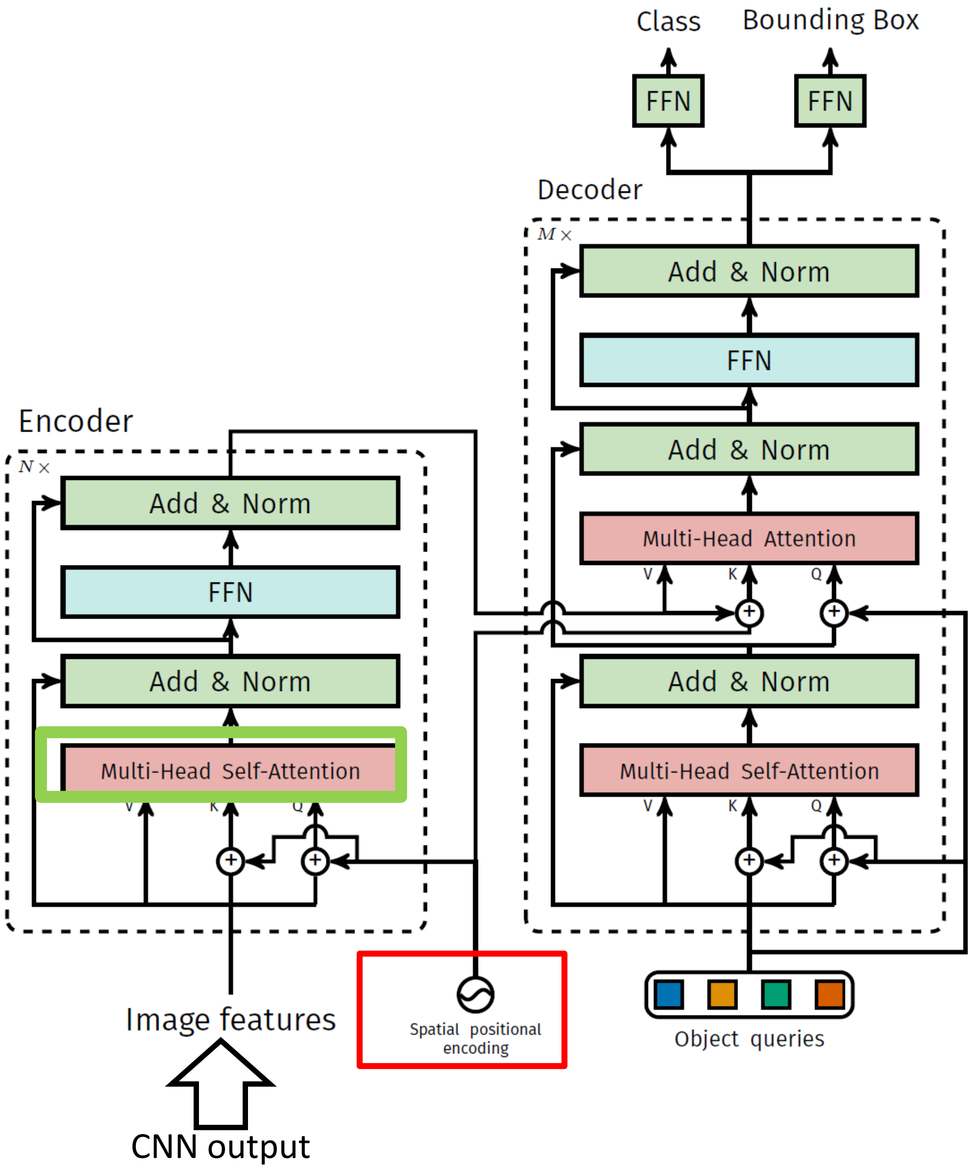
Diving into Vision Transformers (3)

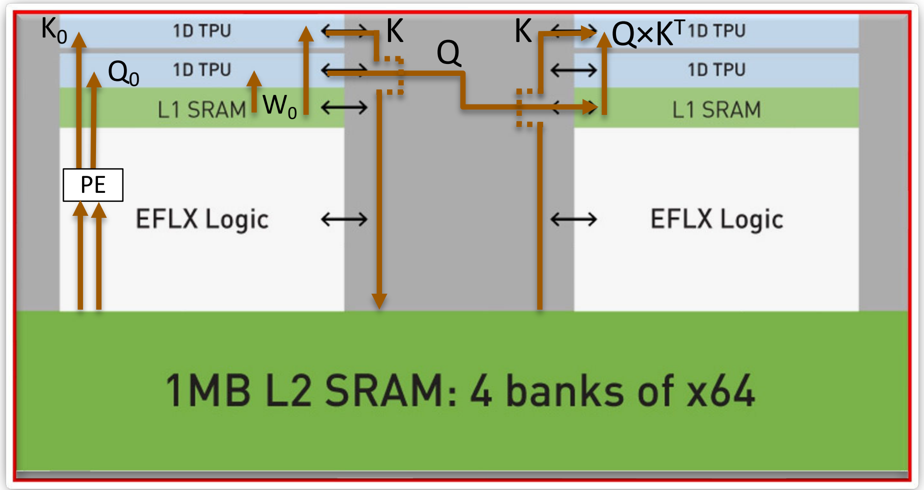


Main part of multi-head attention layer is a challenge on traditional edge accelerators:

- The (Q, K, V) for each matrix is now activation data

$Q \times K^T$ involves multiplying 2 activation data with **each other**

- Fortunately, X1 chip has dedicated path to load activation data into the weight memory



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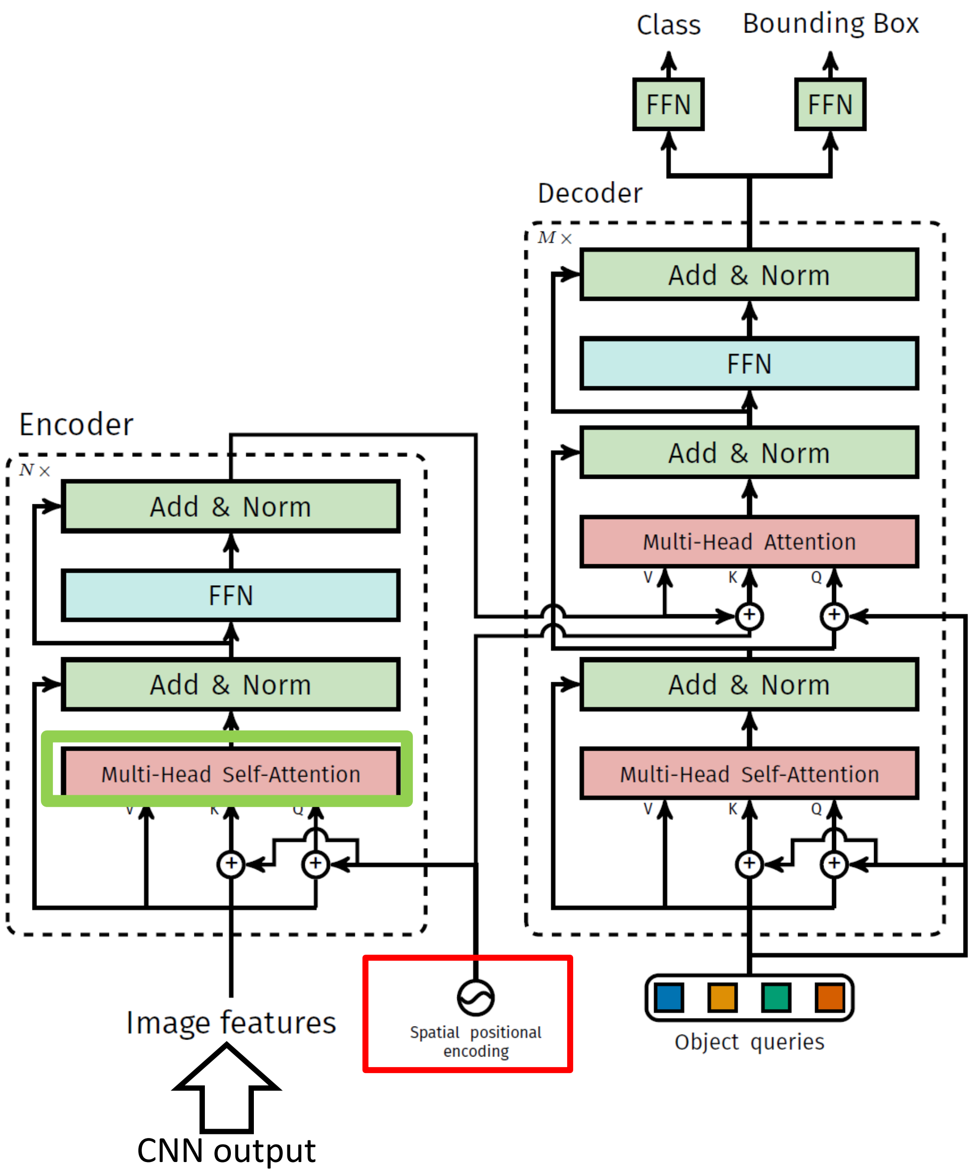
Diving into Vision Transformers (4)

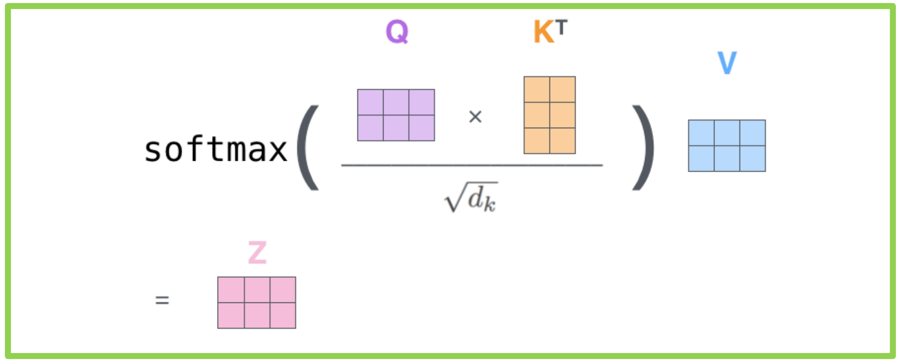


Softmax and norm are also challenging on int8 datapaths

- Fortunately, mixed-precision mode on X1 allows for z_i = Q×K^T result to convert to BF16 to execute exp(z_i)

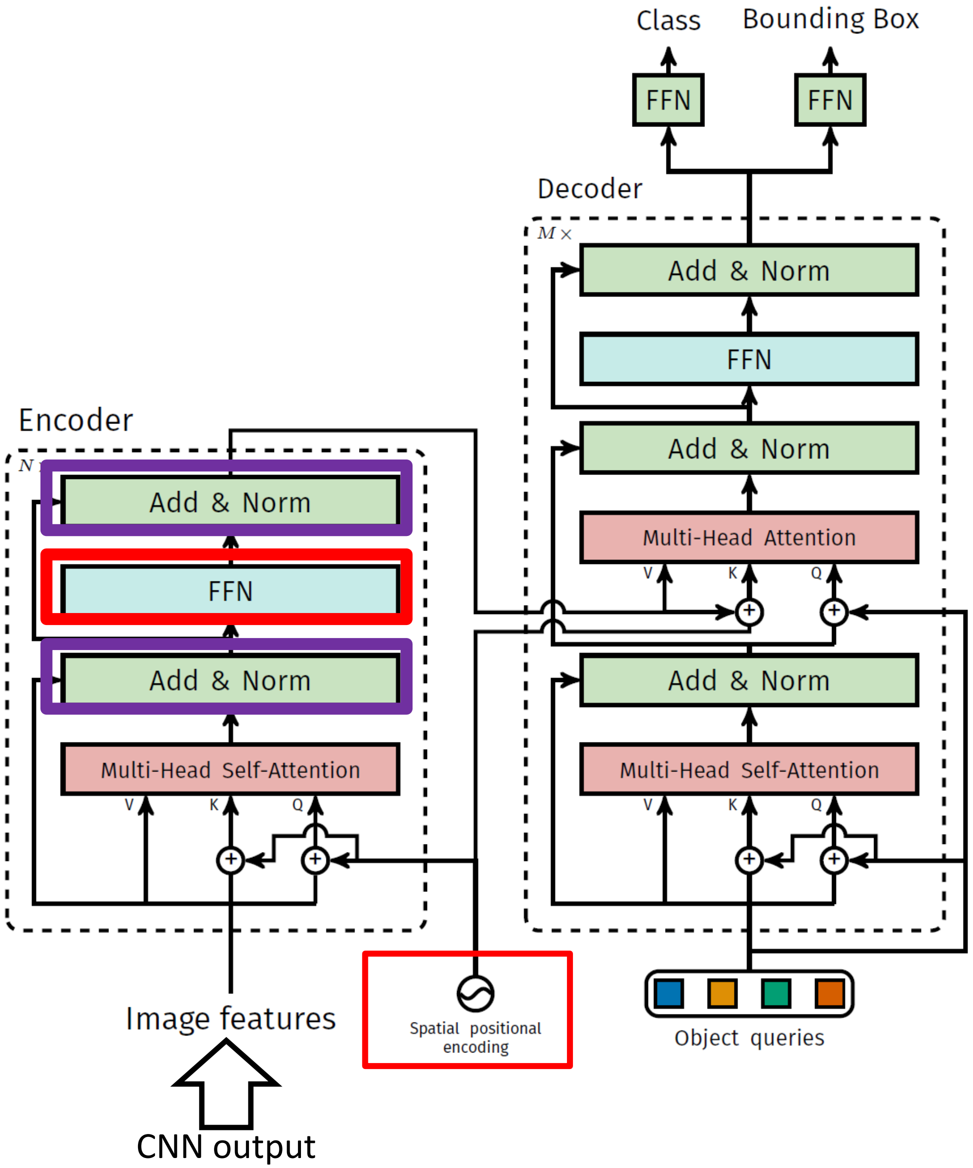
softmax $$\sigma(\vec{z})_i = \frac{e^{z_i}}{\sum_{j=1}^{K} e^{z_j}}$$

- After normalization, softmax output is converted back to int
- Another **activation×activation** is performed natively on X1 to complete the multi-head attention layer



*https://jalammar.github.io/illustrated-transformer

Diving into Vision Transformers (5)



Add & Normalization follows the multi-head attention layer

- The original input is add with the attention output
- Normalization (esp. L2 norm) is best executed on BF16 due to its large dynamic range

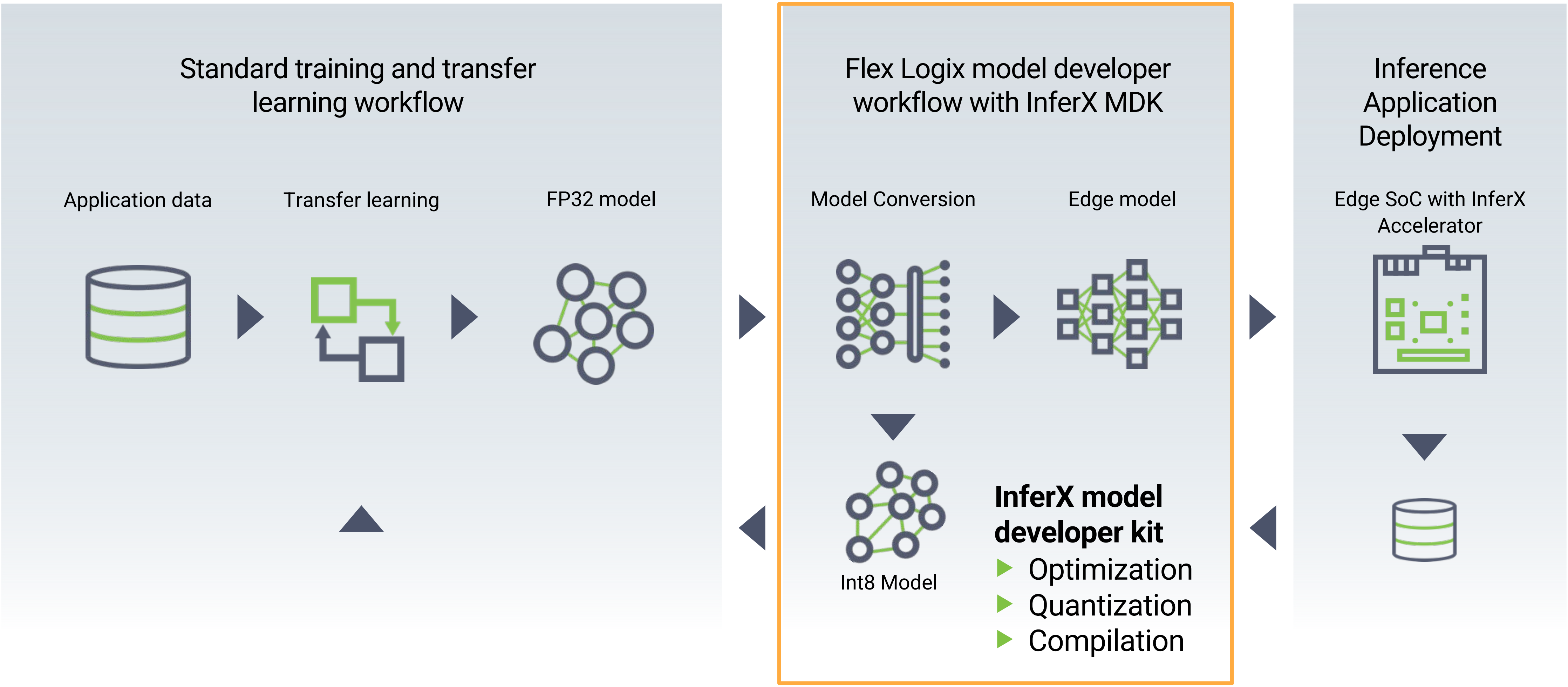
L1 norm $\|W\|_1 = \sum_{i}^{n} |\omega_i|$

Squared L2 norm $\|W\|_2^2 = \sum_{i}^{n} \omega_i^2$

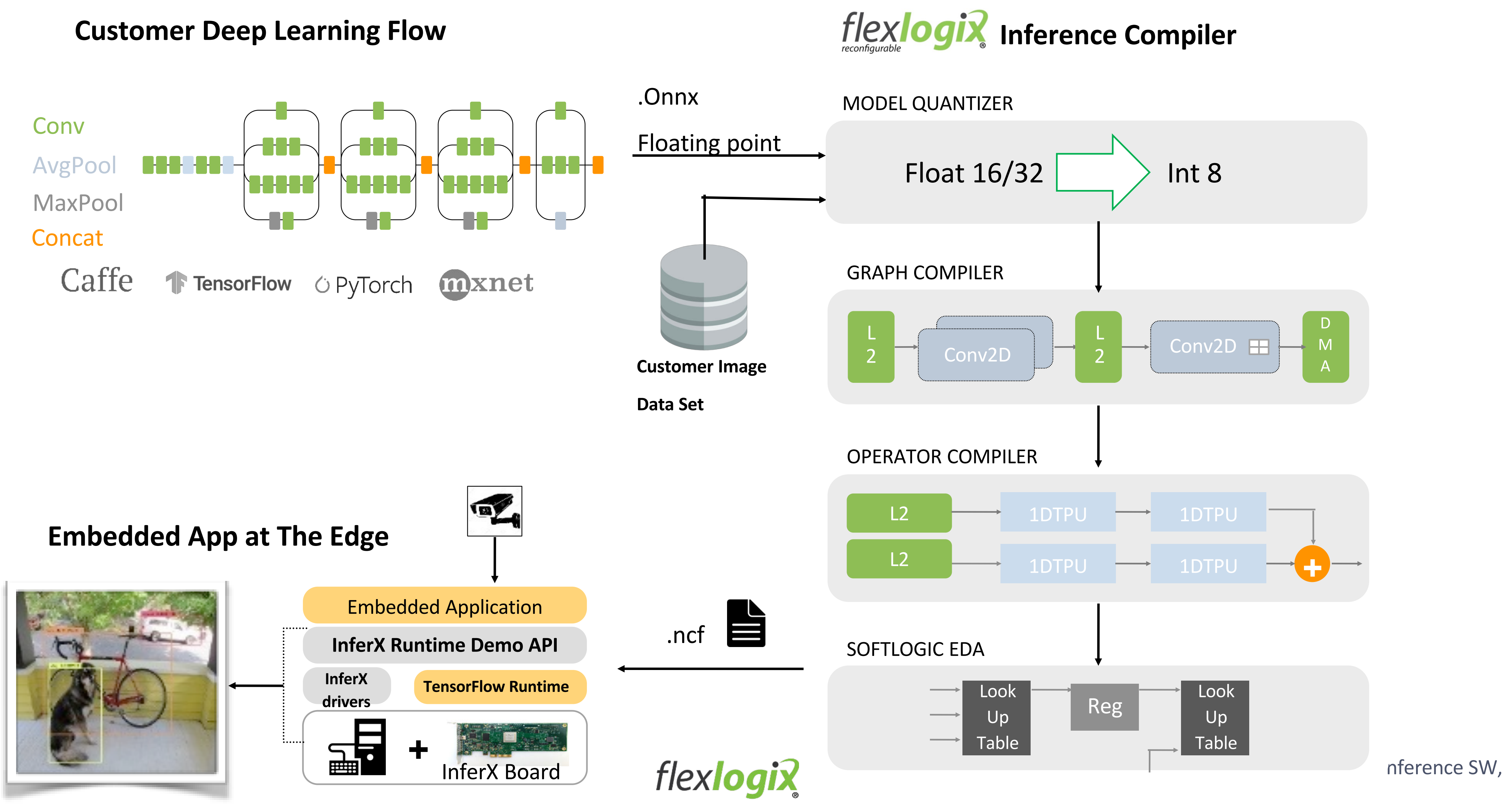
- Feed-forward Network (FFN) is a straight-forward GEMM operation before Add & Norm takes place again

*https://jalammar.github.io/illustrated-transformer

How to deploy InferX models in your system?

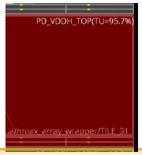


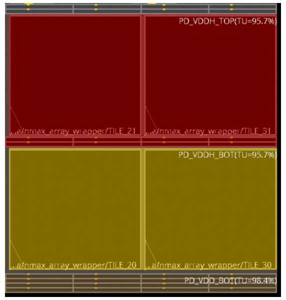
InferX compiler is available for evaluation Today

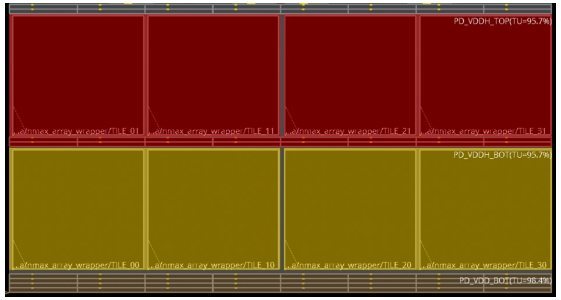


InferX IP family scales from a single tile to a large accelerator

InferX (N7)	Orin AGX 60W
16-128 DTOPs	138 DTOPS
1-4 LPDDR5 x32	LPDDR5 x256 (half for AI)







	16 TOPS 1 LPDDR5	32 TOPS 1 LPDDR5	64 TOPS 2 LPDDR5	128 TOPS 4 LPDDR5
DETR 2020 (Transformer) (1024×1024)	19 IPS	39 IPS	77 IPS	147 IPS
YOLOv5s (640×640) **Orin AGX 125 IPS**	200 IPS	330 IPS	716 IPS	1123 IPS
YOLOv5l6 (1280×1280)	12 IPS	19 IPS	**Orin AGX 31 IPS** 43 IPS	100 IPS
ResNet50 (1024x1024)	29 IPS	39 IPS	84 IPS	197 IPS

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Thank You

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